Kinematics thinkshop talk:

I) ttbar production:

Top produced in pairs: p + pbar --> t + tbar where t --> W + b

To get the best sensitivity to study top kinematics, one can look at events where one W decays leptonically and one decays hadronically. This give a final state with a charged lepton, a neutrino, and 4 quarks plus any extra gluons.

Experimentally we looks for events with a central isolated charged lepton, missing energy, and 3 or more jets (from the 4 quarks and gluons). To improve the signal to noise we can require one of the jets to have a b-tag. Typically one requires a displaced vertex from a b decay in one of the jets. This could be done with almost 50% efficiency in Run 1 and should be higher in Run 2 due to increased silicon coverage. Sometimes a soft lepton tag is used to identify b-jets, but the efficiency of this is reduced by the small semi-leptonic branching ratio of b's (and the background is higher).

Many kinematic quantities have been studied in these events. Usually the jets are corrected for both detector effects and the effects of hadronization. The missing transverse energy can be associated with the transverse energy of the neutrino, the longitudinal energy of the neutrino can be determined by constraining the neutrino and charged lepton to come from the decay of a W (however there are in general two solutions).

II) The simplest kinematic quantities are just the Pt and eta of the measured objects in the events. More complicated and interesting quantities can be studied by combining them. They can be used to study properties of ttbar production, to discriminate between events from ttbar production and the QCD background, and to estimate the mass of the top quark. Examples:

1) Sum of the transverse energy of the 2nd and 3rd highest Pt jets. Not using the highest energy jet improves the discrimination between ttbar production and the QCD background. This and a variation was used in early CDF papers to help confirm ttbar production.

2) Scaler sum of all transverse energy in the event (H). Roughly equivalent to transverse mass of the ttbar system. Can include all the jets in the event or only the 4 jets with the highest Pt. H discriminates well between ttbar events and the QCD W + jets background. H is also sensitive to the value of the top mass.

3) Vector Sum(Pt) of the charged lepton, neutrino, and 4 highest Pt jets in the event. Roughly equivalent to the Pt of the ttbar system. This quantity is sensitive to the amount of initial and final state gluon radiation in ttbar production.

4) Mass of the charged lepton, neutrino (using the lowest energy solution), and the 4 highest Pt jets. Very roughly the mass of the ttbar system.

5) Aplanarity (using the 3-momentum leptonic W and the leading 4 jets). This is a variable that has resonable discrimination between ttbar production and the QCD background with smaller sensitivity to the energy scale and the value of the top quark mass.

6) delta-R: minimum jet-jet separation in eta-phi space. Sensitive to final state radiation. D0 used (delta-R * Et(minjet))/Et(W) as part of a kinematic discriminant for QCD background in their top quark mass determination.

7) Sum(|Pz|)/Sum(Et) which is a measure of centrality of the event and gives a reasonable measure of gluon radiation in the event. D0 used a variant as a discriminant in their top quark mass determination: (Sum(Et(jets)-Et(jet1))/Sum(|Pz|)

Kinematic variables give some indication as to how well the data fits the standard model prediction. Arrow plots compare the first moments of the data and prediction for a wide selection of variables.

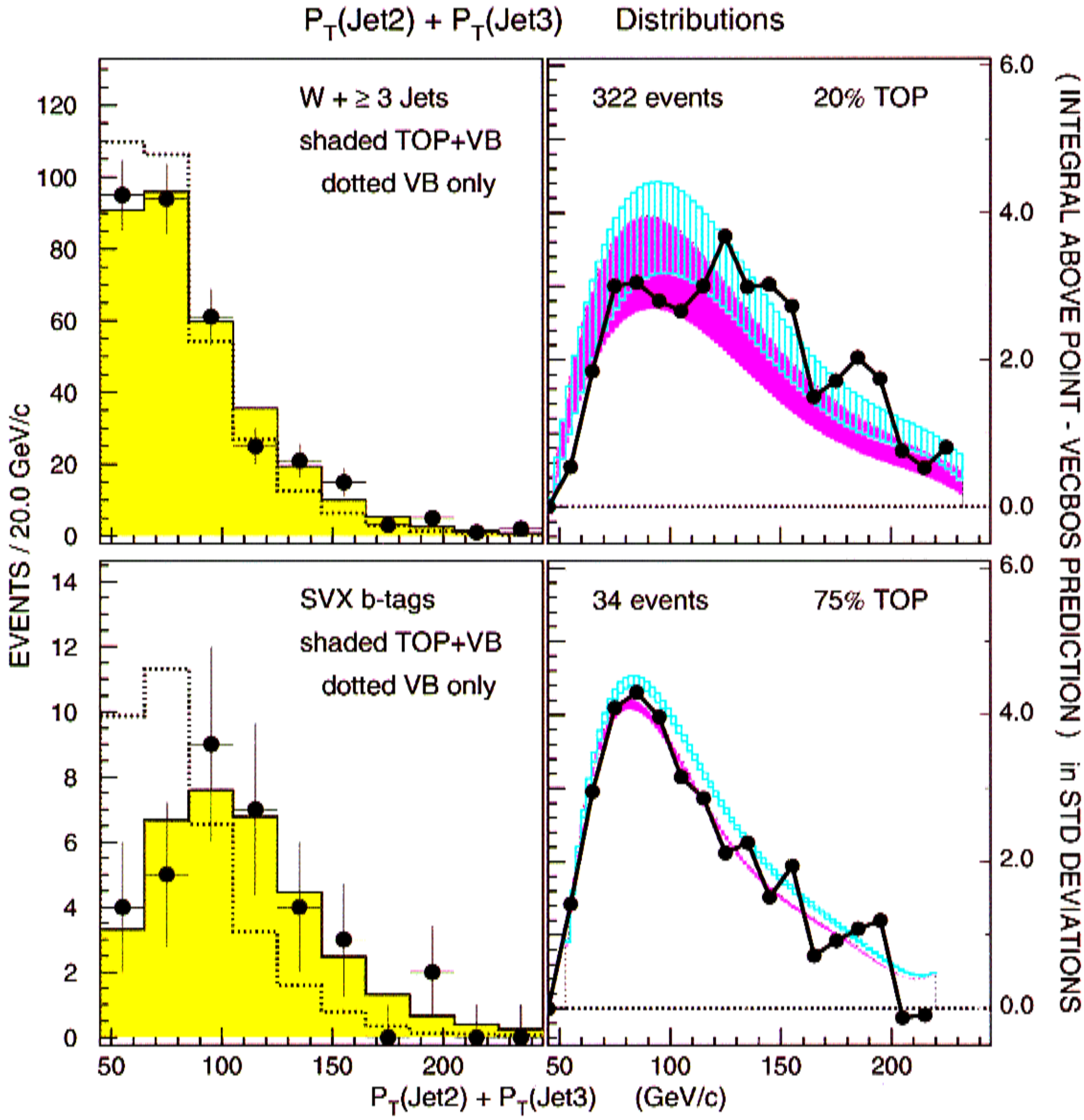


Figure 5: Comparison of the data with Monte Carlo predictions for Pt(jet2)+Pt(jet3). The differential plots are on the left. The points with error bars are the data, the dotted line is the prediction for VECBOS alone, and the shaded area in the prediction of the expected mix for VECBOS and TOP175. The integral significance plots are on the right. The solid line is the data and the bands are the predictions. The shaded band is the prediction for VECBOS+TOP175 and the striped band is the prediction for VECBOS+TOP185. The widths of the bands indicate the variation due to the two different q**2 scales for VECBOS. The ordinate is the difference in the integral to that point in 'Std Deviations'

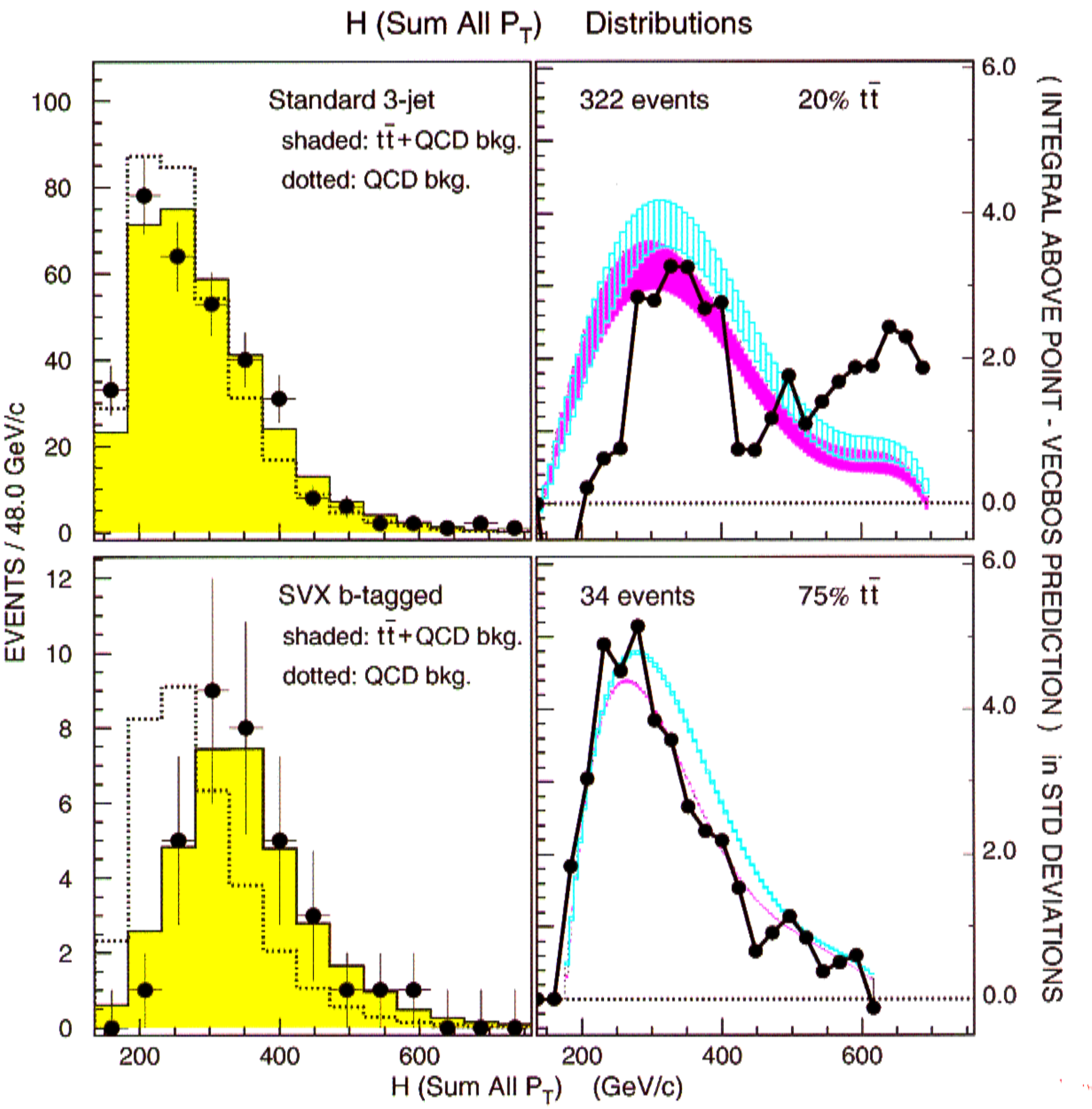


FIG. 15. Comparison of the data with Monte Carlo predictions for H. Differential plots are on the left; the solid points with error bars are the data and the histograms are the Monte Carlo predictions normalized to the data. The integral significance plots are on the right; the data are the solid points. The shaded band is the prediction for the expected mixture of $t\bar{t}$ and QCD background for 175 GeV/c^2 top; the hatched band is the equivalent for 185 GeV/c^2 top. The width of the bands represent the uncertainty in the QCD background due to Q^2 scale variations. A data point one vertical unit from the shaded band corresponds to a one σ deviation.

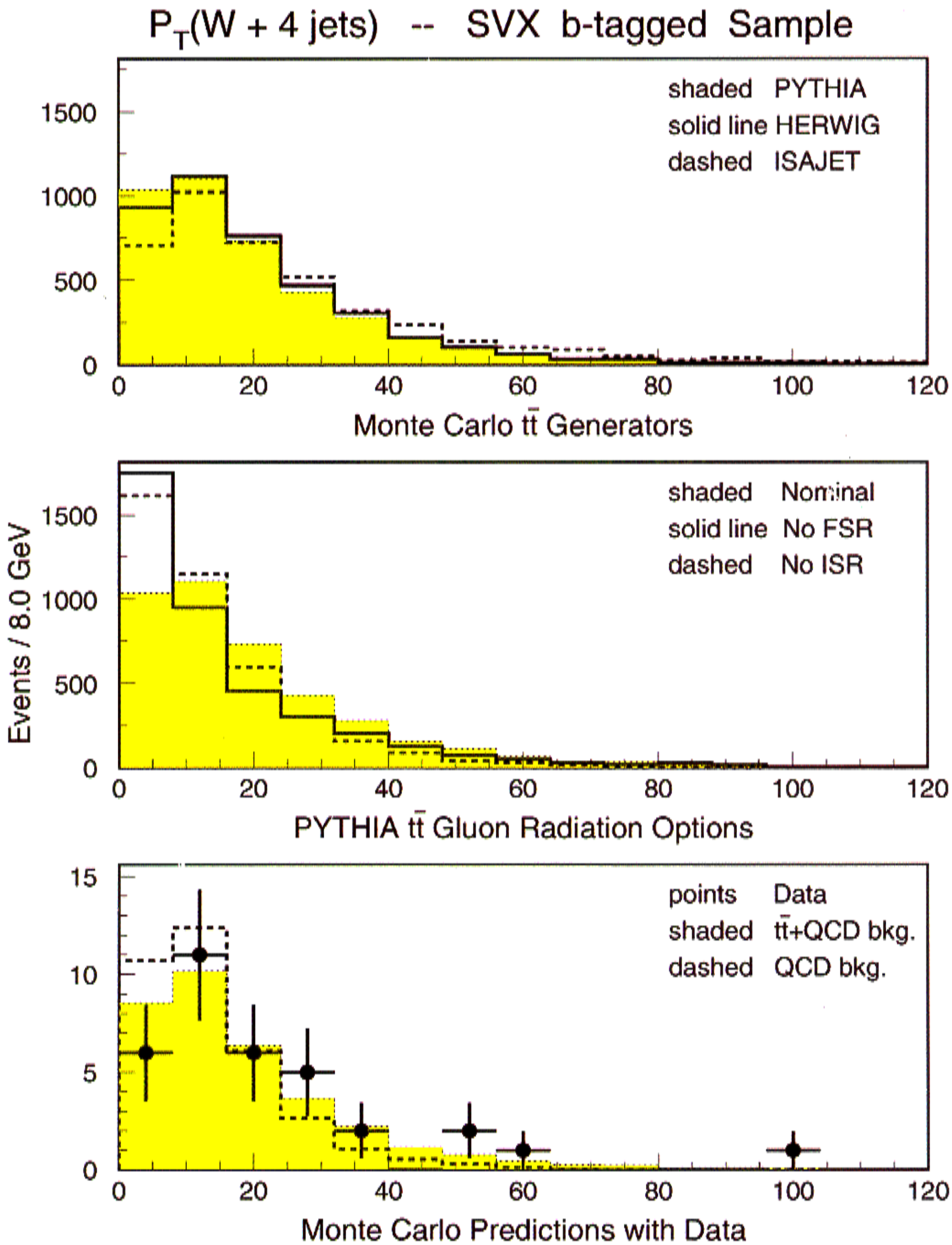
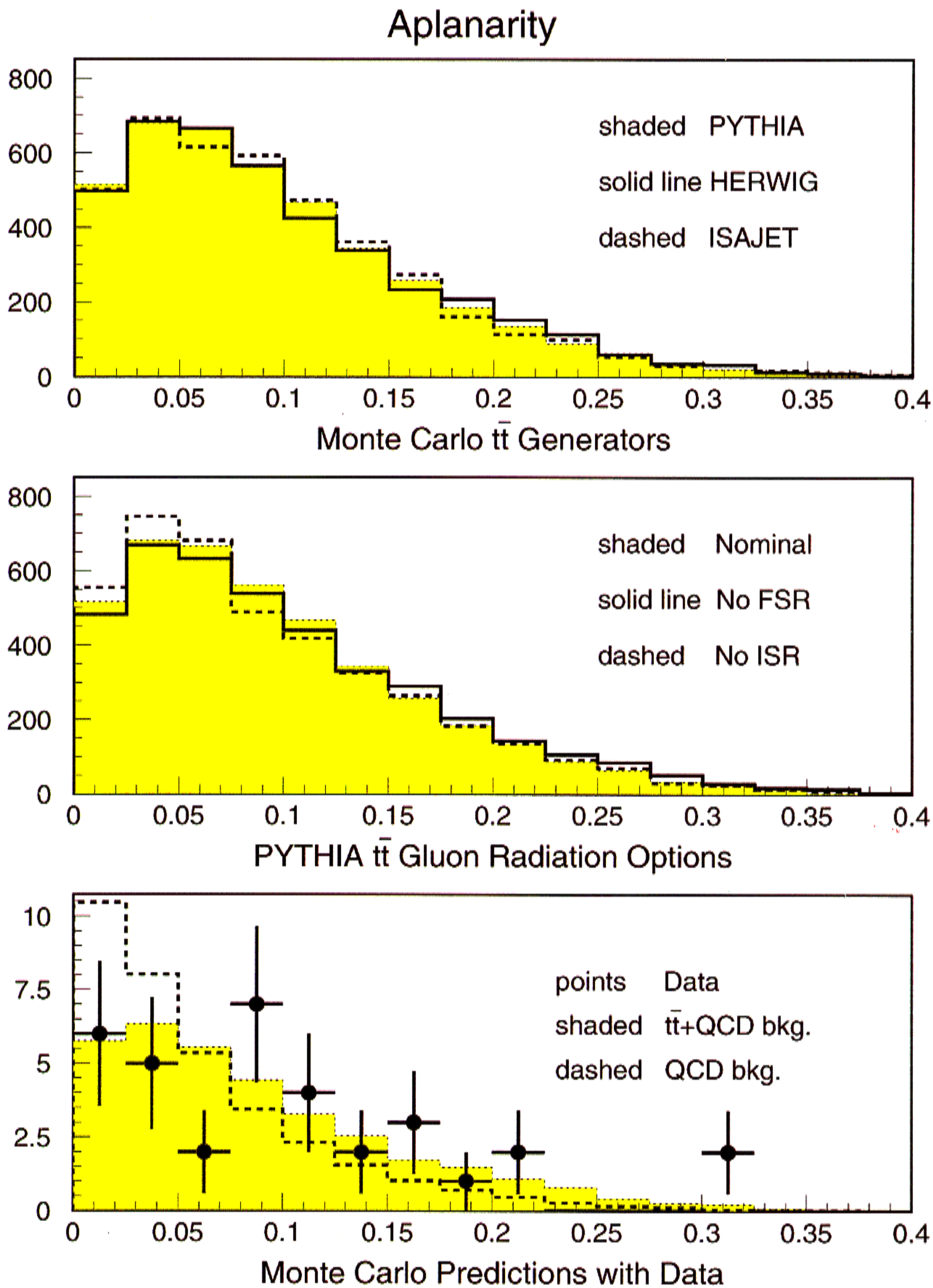
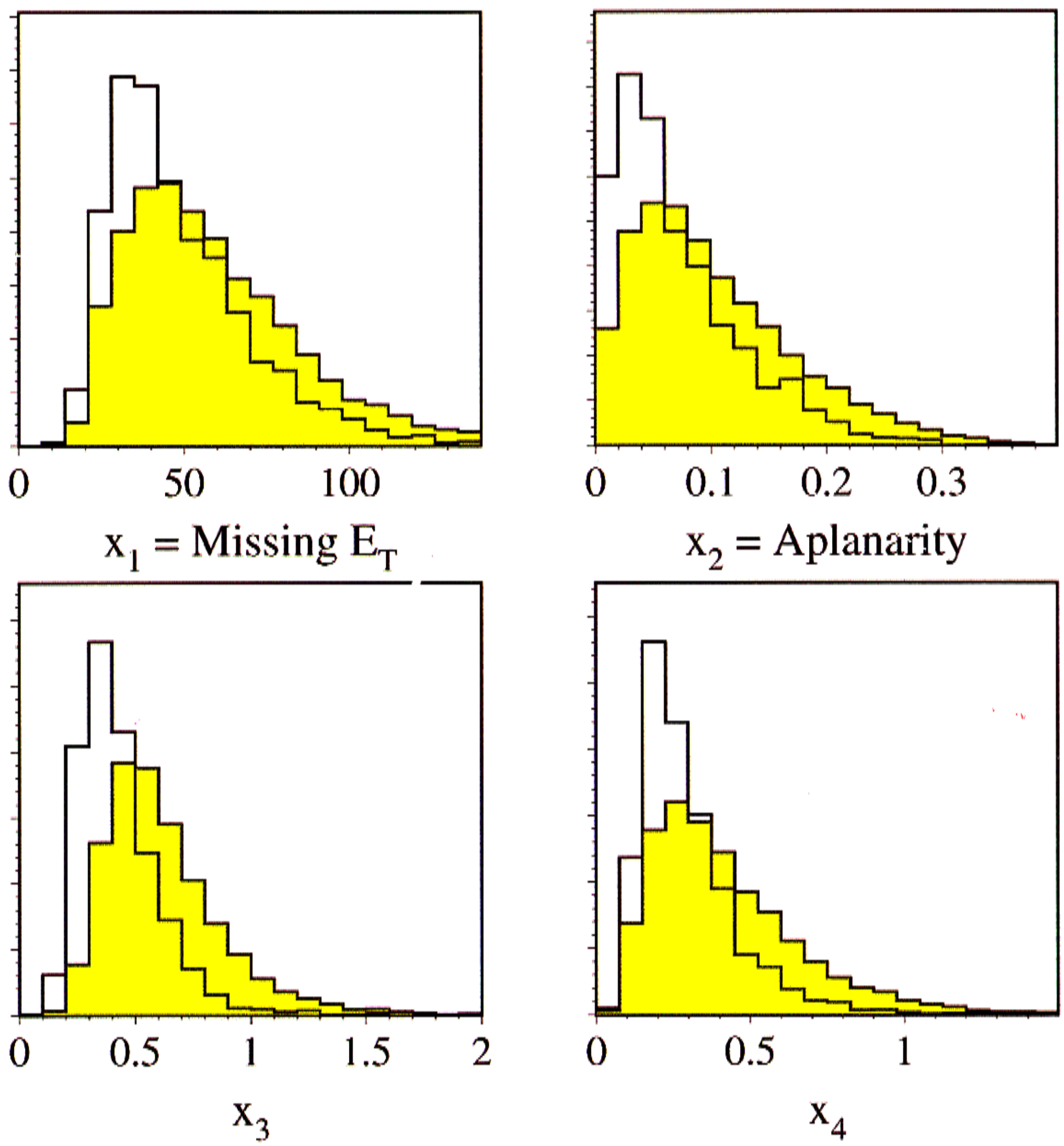


Figure 1: Distributions of the transverse momentum of the W and the 4 highest energy jets for gluon radiation studies. The top plot shows the predictions for the three $t\bar{t}$ generators. The middle plot shows the prediction for Pythia with different gluon radiation options. The bottom plot compares the data (solid points with error bars) to predictions for the expected mixture of $t\bar{t}$ and QCD background and for QCD background alone.


Aplanarity
shaded PYTHIA
solid line HERWIG
dashed ISAJET
Monte Carlo $t\bar{t}$ Generators
shaded Nominal
solid line No FSR
dashed No ISR
PYTHIA $t\bar{t}$ Gluon Radiation Options
points Data
shaded $t\bar{t}$+QCD bkg.
dashed QCD bkg.
Monte Carlo Predictions with Data

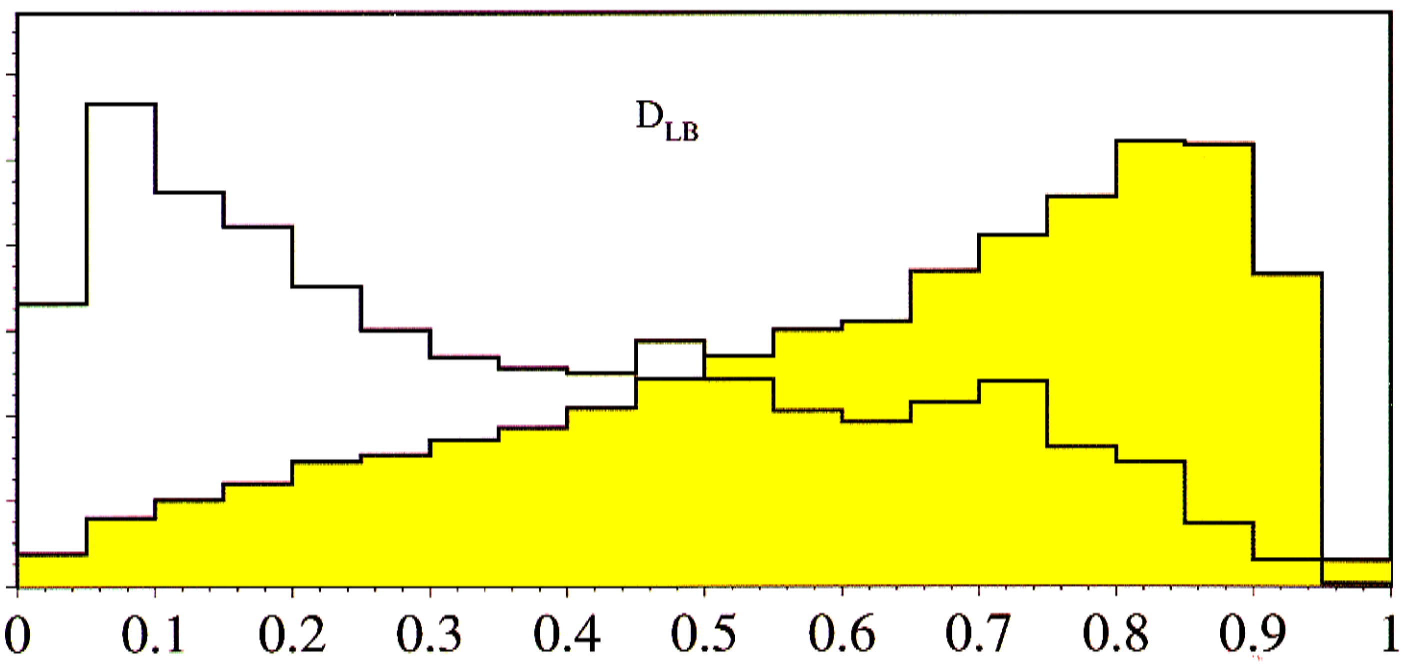
Discriminant Variables

For Background and $m_t = 175\,\mathrm{GeV}/c^2$ Herwig top.

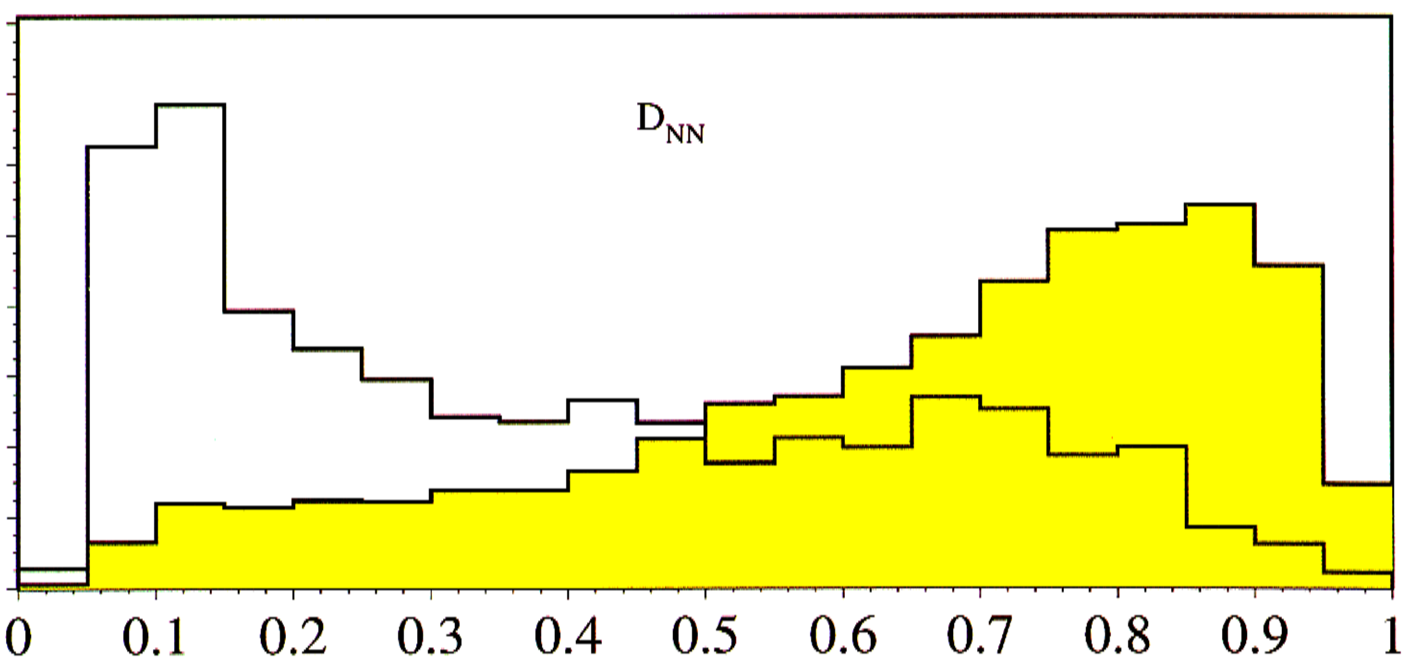


$H_{T2}/\Sigma|P_z|$

$\Delta R\, E_t(\min)/E_t^W$



D_{LB}
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1



D_{NN}
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

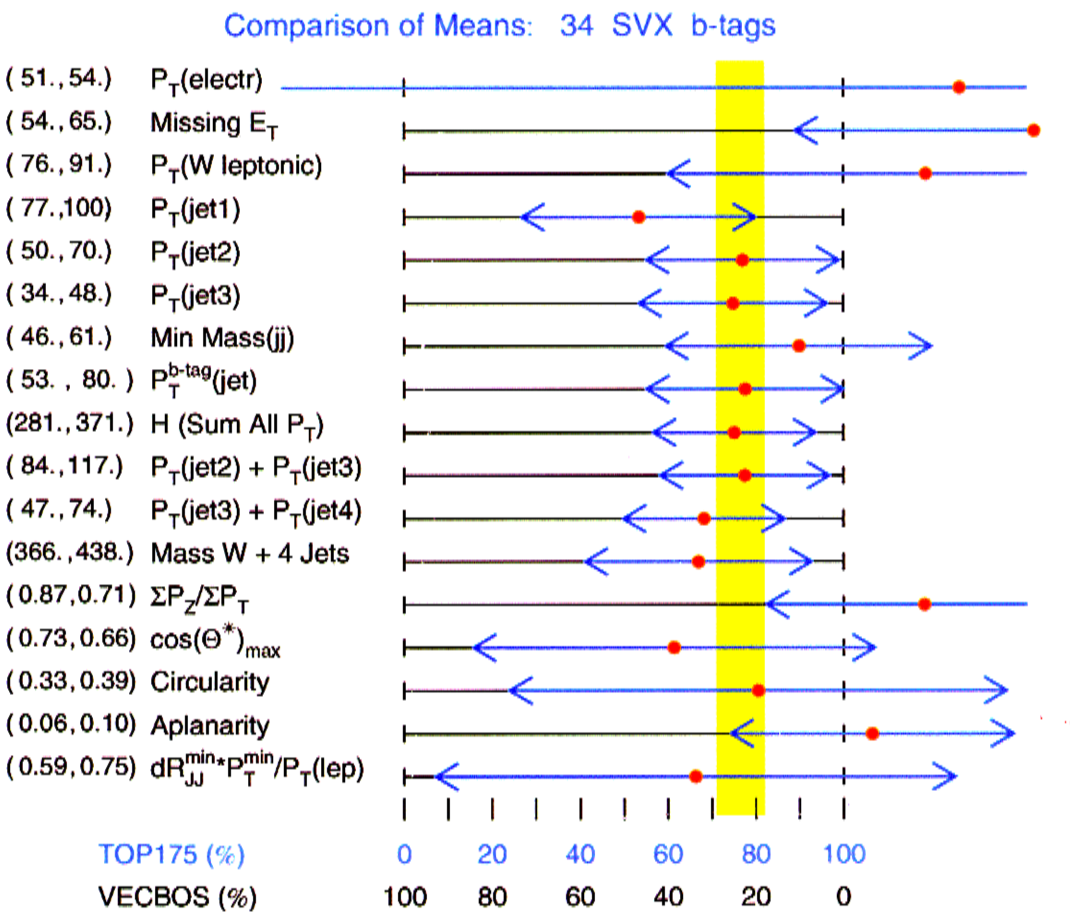


Figure 2: Comparison of data means with VECBOS and TOP175 for the 34 event data sample with at least one SVX b-tagged jet.

III) In event where a 4th jet is observed, one can try to fit the event to the assumed decay hypothesis assigning each jet to one of the b quarks or the W. The two top quarks are constrained to have the same mass and the two jets from the hadronic decay of the W are constrained to the W mass. Doing this, the value of top quark mass can be reconstructed on an event by event basis. A top quark mass can be obtained and by fitting reconstructed top quark spectrum to templates generated from Monte Carlo samples for different values of the top quark mass. Caveat: some of fits will be wrong because of combinatorics or the effects of gluon radiation!

IV) Once the mass fit has been performed, more sophisticated kinematic variables can constructed. Each object will have a fit value for Pt and eta and have been assigned to a particular parton. Examples:

1) Mass ttbar system. To improve mass resolution, this constrains the top mass to 175 GeV for each event. Look for narrow resonances decaying to ttbar.

2) Pt of the top quark with the all hadronic decay. Can put limits on anomalous high Pt top quark production.

3) Helicity of W in t-quark decays. Checks that W decay is V-A. Published result actually uses charged lepton Pt which is also very sensitive to the angular distribution of the W decay.

4) Misc. other variables.

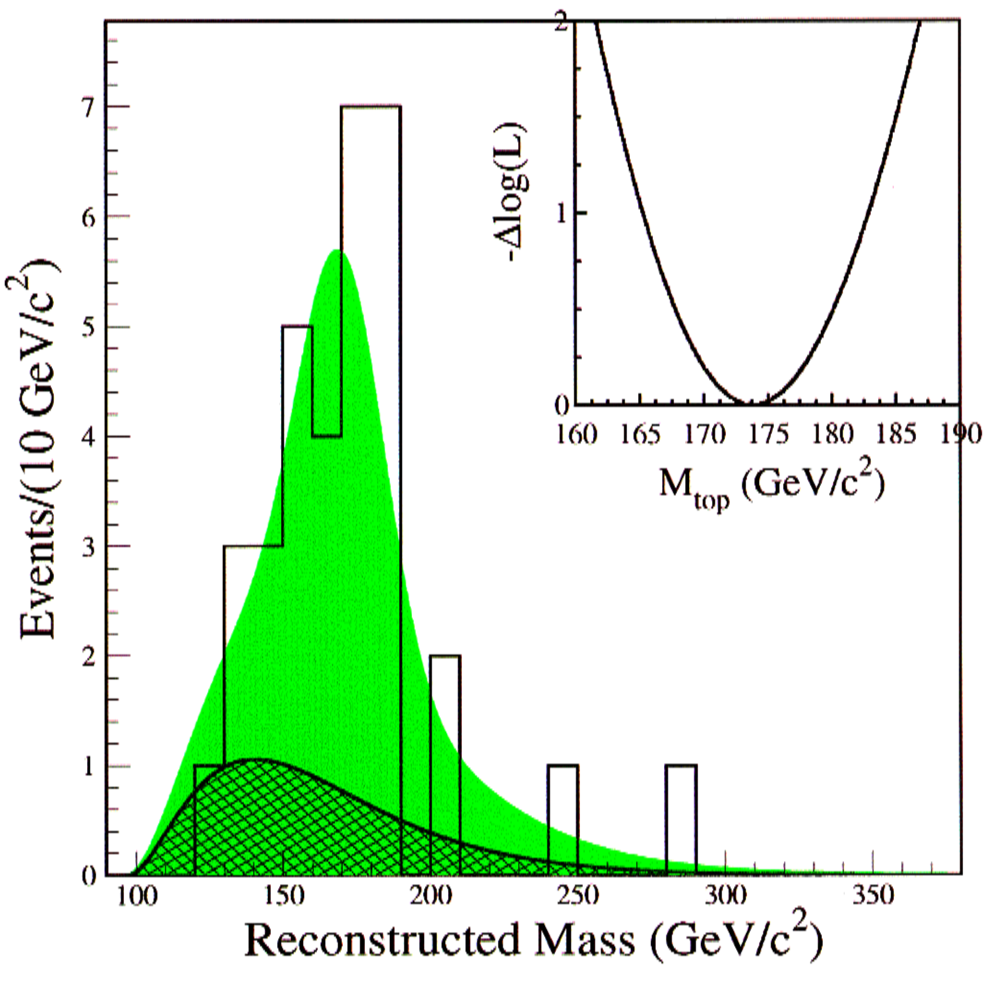


Figure 8.5: Result of applying the likelihood procedure to the 34 b-tagged events, treated as a single sample. The figure shows the data (histogram), fitted background (shaded hatched region), and fitted signal (shaded non-hatched region). The inset shows the shape of $-\log \mathcal{L}$ versus top mass, from which we extract the top quark mass and its statistical uncertainty.

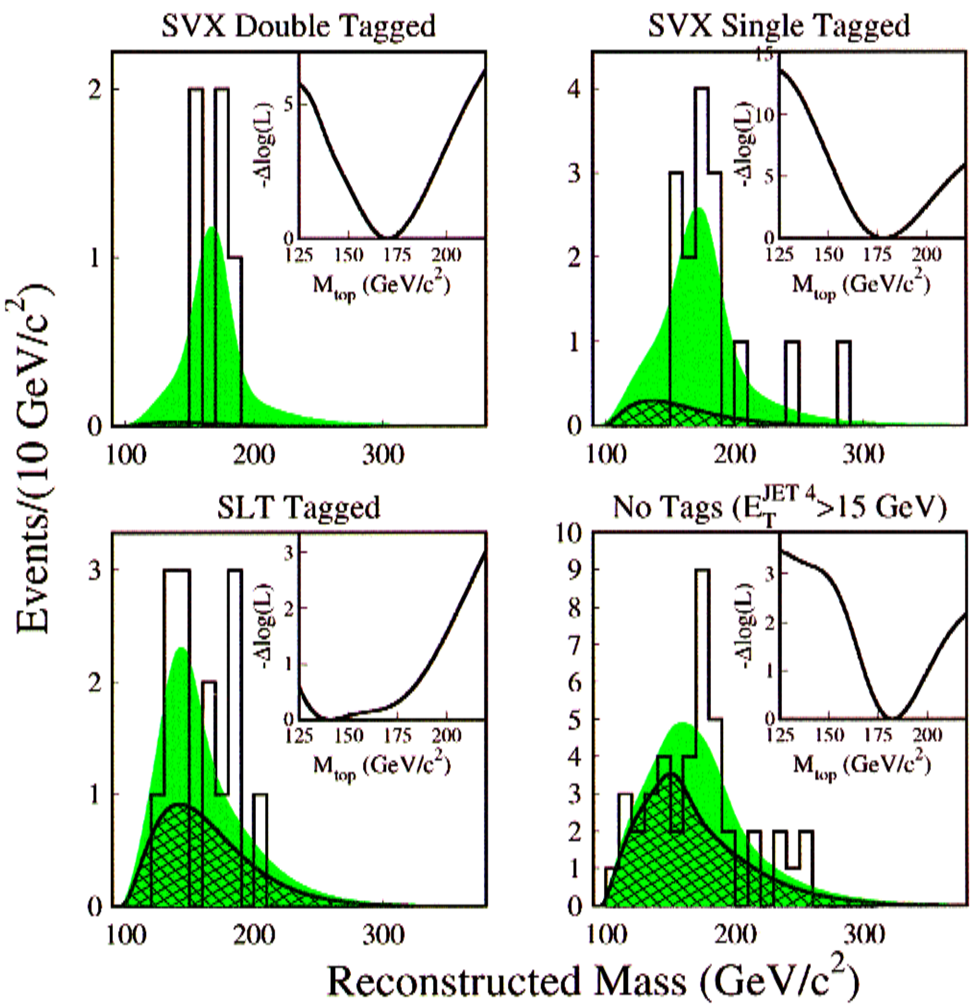


Figure 8.1: Results of applying the likelihood procedure to the four subsamples. The figure show the data (histogram), fitted background (shaded hatched region), and fitted signal (shaded non-hatched region). The insets show the shapes of $-\log\mathcal{L}$ versus top mass, from which we extract the fitted top quark mass and its statistical uncertainty.

and between jets [61, 9]) we will not use ISAJET here. We evaluate the systematic uncertainty from the choice of Monte Carlo generators via the mass shift between the HERWIG and PYTHIA simulations. This gives a systematic uncertainty of ± 0.1 GeV/c^2.

9.7 Summary of systematic uncertainties

The relevant systematic uncertainties studied for the top mass measurement are listed in Table 9.1. Combining all of these effects in quadrature gives a total systematic uncertainty of ± 5.3 GeV/c^2, or $\pm 3\%$ of 176.1 GeV/c^2.

Source	Uncertainty (GeV/c^2)
Jet energy measurement	4.4
Initial and final state radiation	2.6
Shape of background spectrum	1.3
b-Tagging	0.4
Parton distribution functions	0.3
Monte Carlo generators	0.1
Total	5.3

Table 9.1: Systematic uncertainties on the measurement of the top quark mass for this analysis.

FIGURES

FIG. 1. The reconstructed p_T distribution in each of four true p_T bins for Monte Carlo $t\bar{t}$ events. These curves include a simulation of the resolution effects introduced by our reconstruction algorithm and the resolution of the CDF detector. The true p_T distribution within each bin is the HERWIG prediction. This plot includes only the hadronically-decaying top quarks.

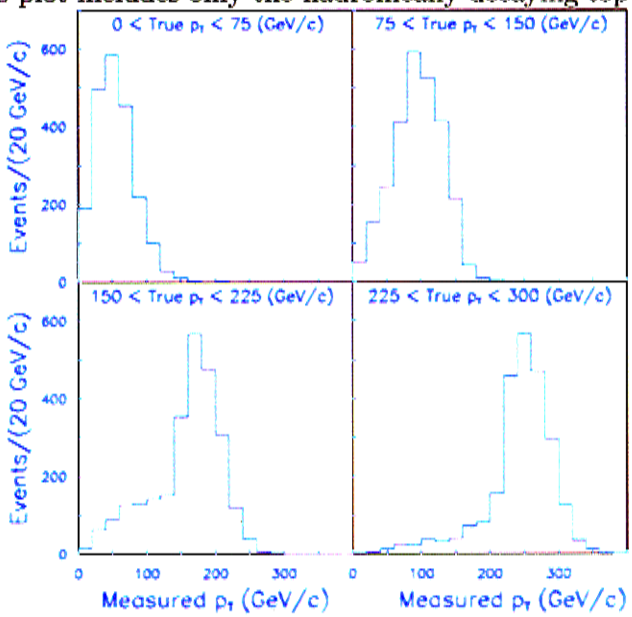
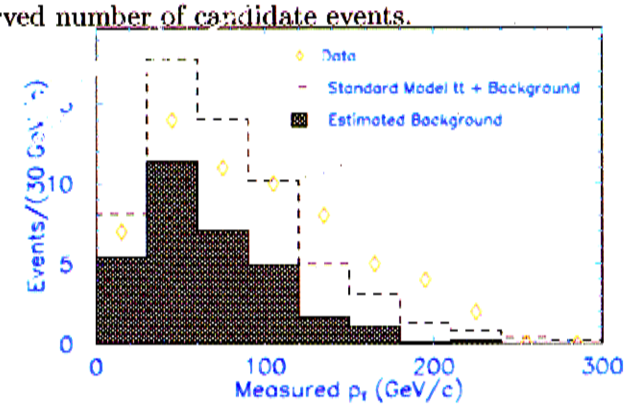


FIG. 2. The measured p_T distribution for the hadronically-decaying top quarks in the 61 event sample. The hatched distribution is the estimated background distribution, normalized to the estimated number of background events. The dashed distribution is the Standard Model prediction, normalized to the observed number of candidate events.



Results of the Top Quark p_t Measurement

p_T Bin	Parameter	Measurement	Standard Model Expectation
$0 \leq p_T < 75$ GeV	R_1	$0.21^{+0.22}_{-0.21}(\mathrm{stat})^{+0.10}_{-0.08}(\mathrm{syst})$	0.41
$75 \leq p_T < 150$ GeV	R_2	$0.45^{+0.23}_{-0.23}(\mathrm{stat})^{+0.04}_{-0.07}(\mathrm{syst})$	0.43
$150 \leq p_T < 225$ GeV	R_3	$0.34^{+0.14}_{-0.12}(\mathrm{stat})^{+0.07}_{-0.05}(\mathrm{syst})$	0.13
$225 \leq p_T < 300$ GeV	R_4	$0.000^{+0.031}_{-0.000}(\mathrm{stat})^{+0.024}_{-0.000}(\mathrm{syst})$	0.025
$0 \leq p_T < 150$ GeV	$R_1 + R_2$	$0.66^{+0.17}_{-0.17}(\mathrm{stat})^{+0.07}_{-0.07}(\mathrm{syst})$	0.84

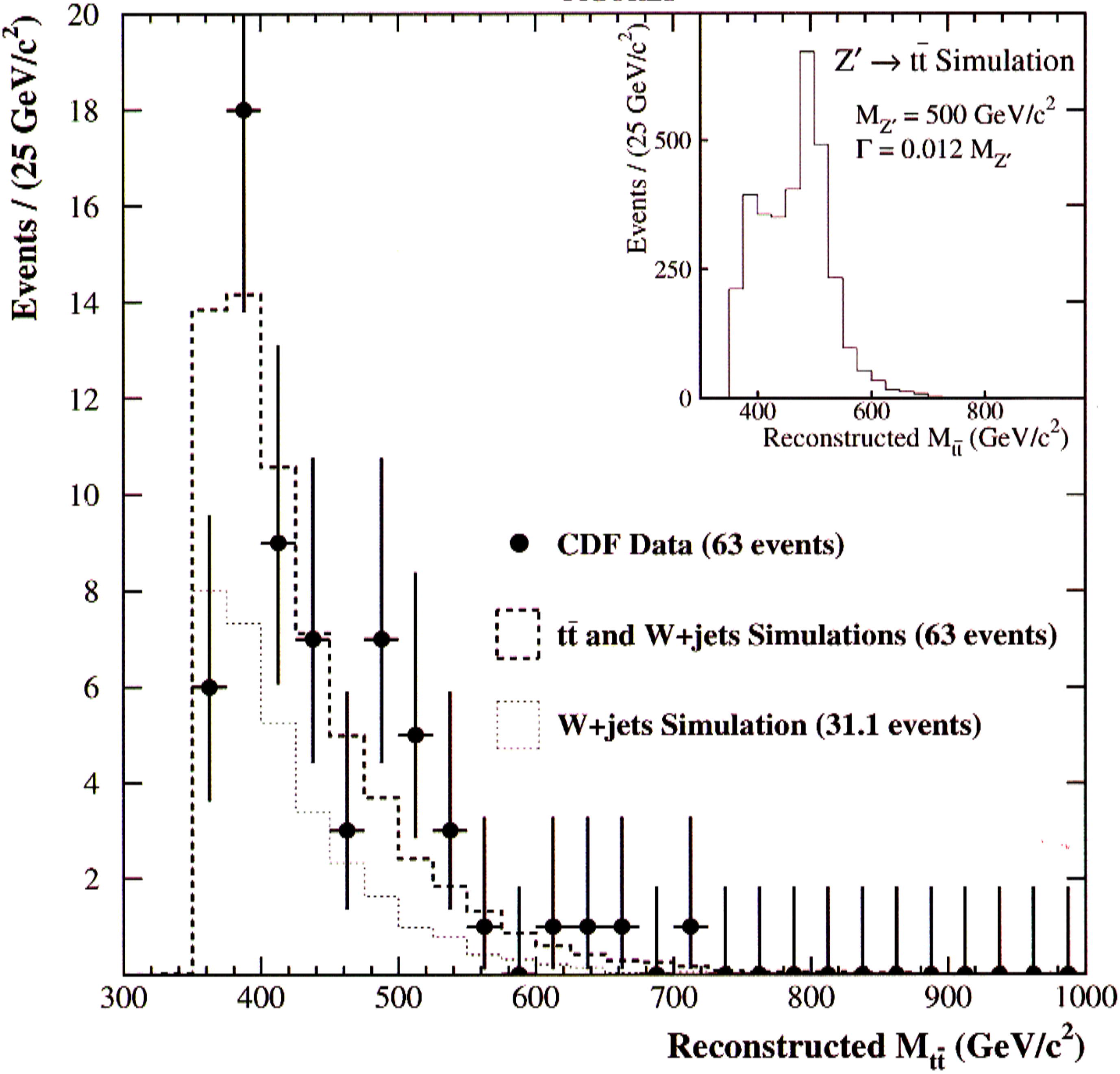
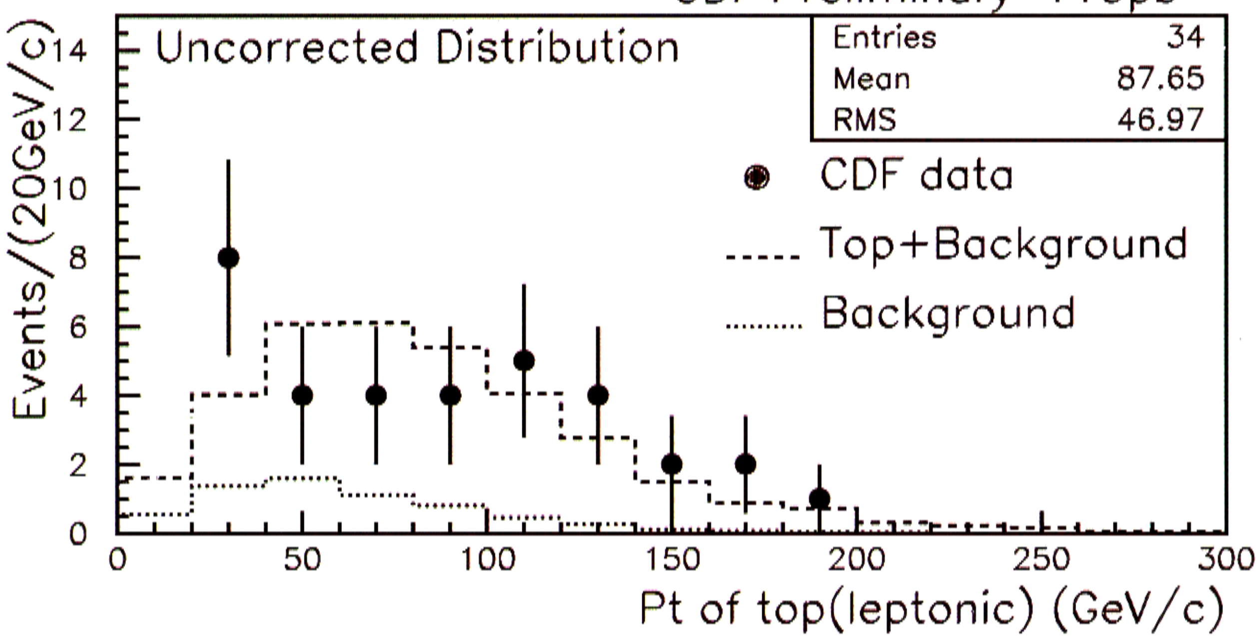
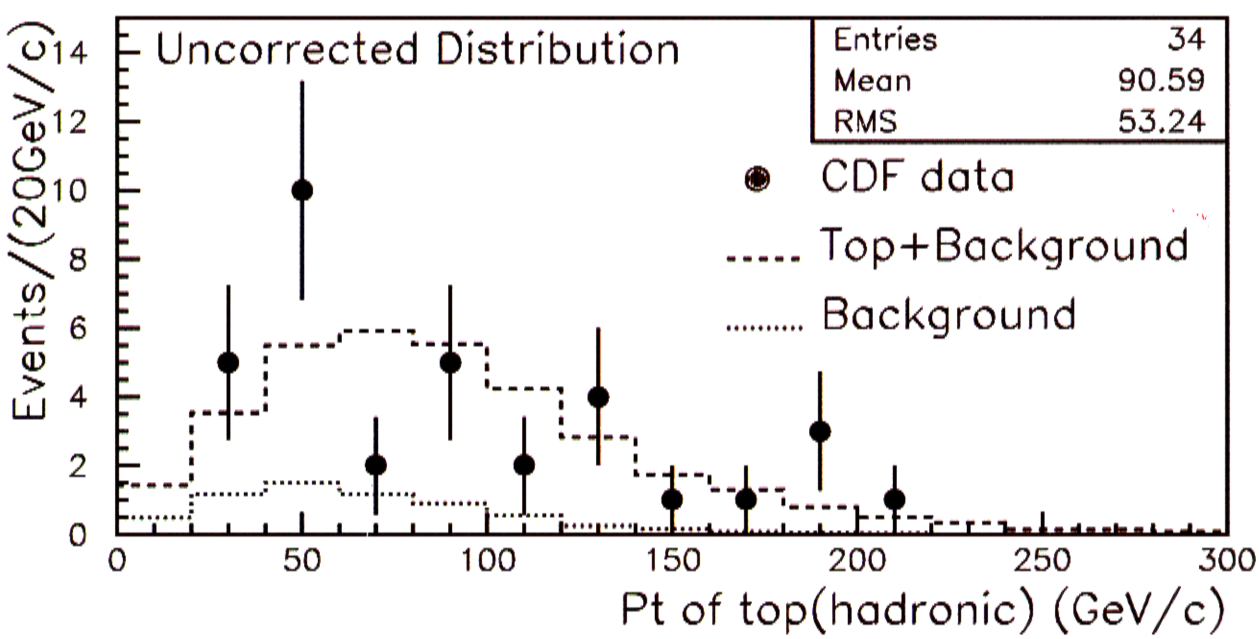
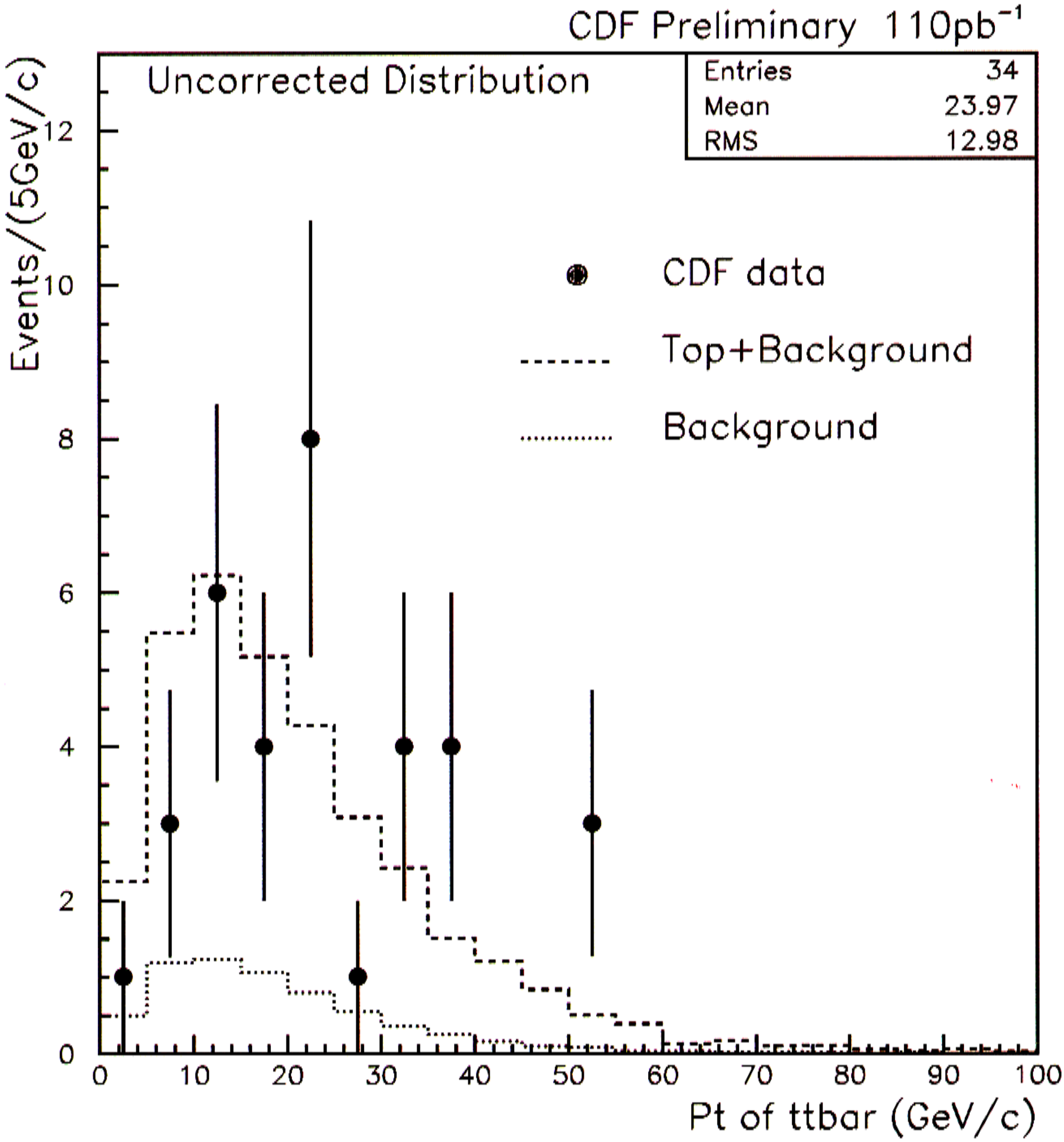


FIG. 1. The observed $M_{t\bar{t}}$ spectrum (points) compared to the QCD W+jets background (fine dashed) and the total standard model prediction including both QCD W+jets and $t\bar{t}$ production (thick dashed). The $t\bar{t}$ prediction has been normalized such that the number of events in the total standard model prediction is equal to the number of events in the data. The inset shows the expected M_{tt} shape resulting from the simulation of a narrow resonance ($M_{Z'} = 500\text{GeV}/c^2$, $\Gamma = 0.012 M_{Z'}$) in the CDF detector.

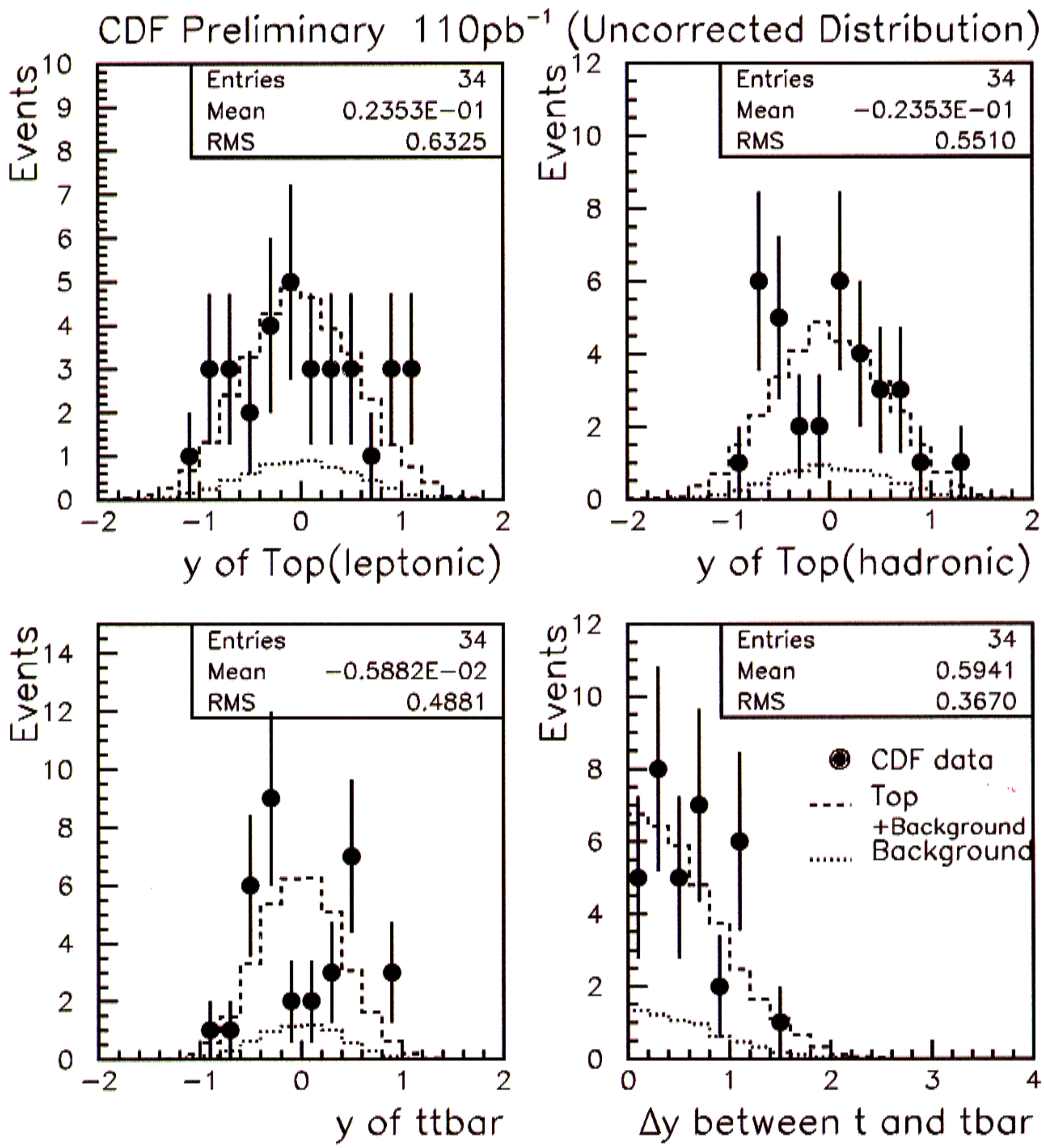
CDF Preliminary 110pb^{-1}



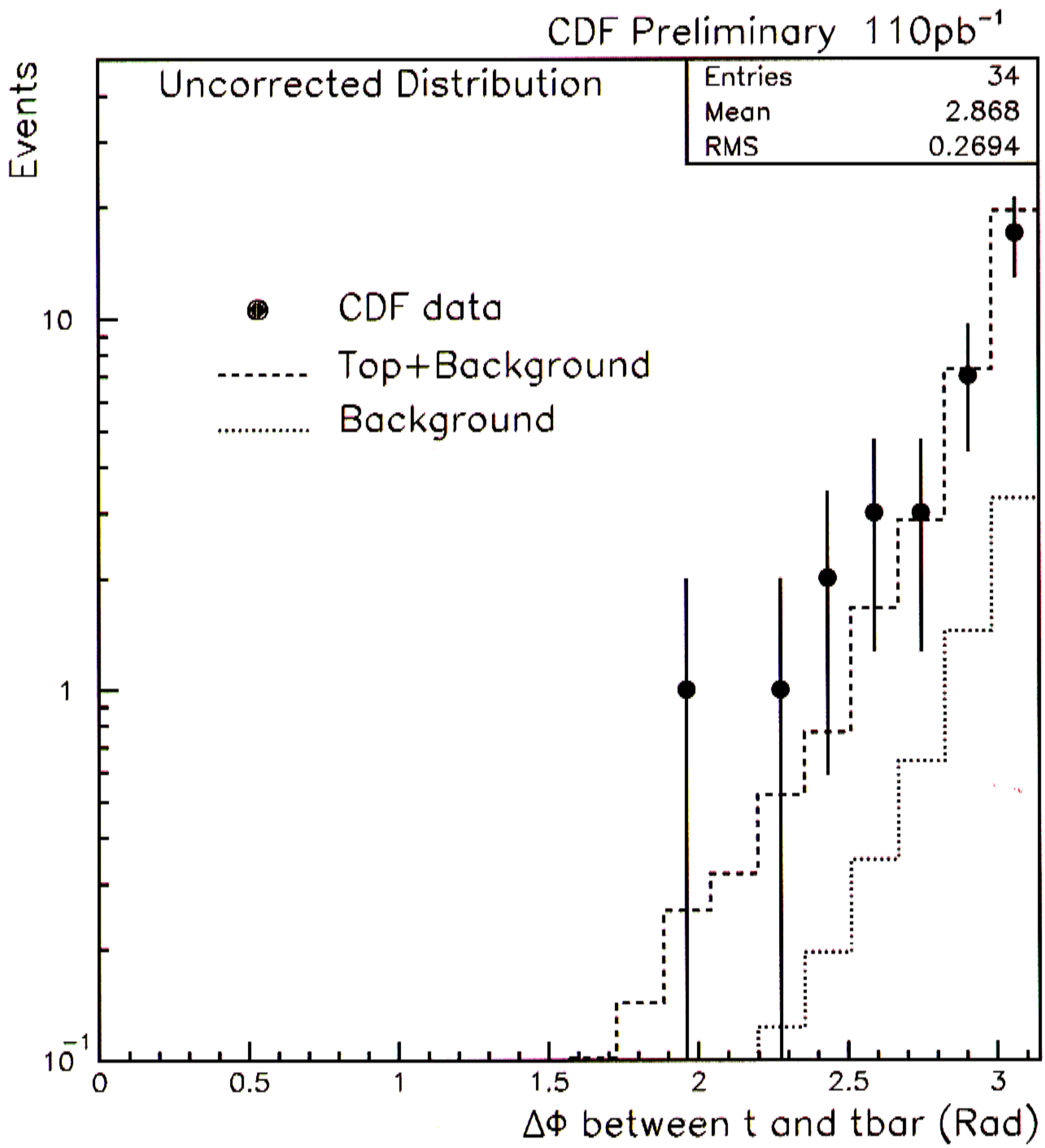




CDF Preliminary 110pb^-1
Uncorrected Distribution
Entries 34
Mean 23.97
RMS 12.98
CDF data
Top+Background
Background
Events/(5GeV/c)
Pt of ttbar (GeV/c)
0
2
4
6
8
10
12
0
10
20
30
40
50
60
70
80
90
100



CDF Preliminary 110pb^{-1} (Uncorrected Distribution)
Entries 34
Mean 0.2353E−01
RMS 0.6325
Events
y of Top(leptonic)
Entries 34
Mean −0.2353E−01
RMS 0.5510
Events
y of Top(hadronic)
Entries 34
Mean −0.5882E−02
RMS 0.4881
Events
y of ttbar
Entries 34
Mean 0.5941
RMS 0.3670
CDF data
Top +Background
Background
Events
Δy between t and tbar


CDF Preliminary 110pb⁻¹
Uncorrected Distribution
Entries 34
Mean 2.868
RMS 0.2694
Events
CDF data
Top+Background
Background
10
1
10⁻¹
0
0.5
1
1.5
2
2.5
3
ΔΦ between t and tbar (Rad)